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RESEARCH ARTICLE

Meta-level performance management of simulation: The problem context retrieval approach

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Abstract

This paper introduces an approach for meta-level performance management of simulation. The paper focuses on the efficiency of modelling and simulation of organisational ICT and related BP systems. The analysis of these systems is essential for the analysis and design of ERP (Enterprise Resource Planning) systems. Projects initiated for the simulation of these systems frequently lead to the use of complex models with a high computing capacity requirement (showing the importance of efficiency) and typically, they are executed in a changing problem context environment. The performance management approach proposed by the paper provides methodological support for problem context transitions based on the models of changing problem contexts and on the set of efficiency principles (taking into account the efficiency of transitions too) together with a formal information retrieval based model of efficiency. This efficiency model takes into account both short-and long-term efficiency requirements, namely the efficiency of each step and the efficiency of the whole simulation process.

Keywords

meta-level performance manegement · dynamic problem context · information-retrieval based model of efficiency · efficiency of simulation

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1 Introduction

During the last decade, the need for the common simulation analysis of Information and Communication Technology (ICT) systems and Business Process (BP) systems of organizations has been increased significantly, because simulation turned to be an appropriate tool for fitting the features of these systems with each other and with the goals of the business.

The optimization of large BP systems is a complex task, as it typically requires a mixture of soft and hard methodologies, so, the optimizer needs to learn about the complex system before starting to create any formal model. BP processes often include humans with all their autonomic behaviour which makes the matter even worse. However, there are known methodologies for the management of these cases, trying to guarantee the precise and realistic system modelling.

Simulation is accepted as a good tool for optimizing ICT/BP processes. The explanation is simple: this kind of analysis is cheaper, more feasible, and easier to interpret and utilize than an abstract numeric approach. On the other hand, simulation has its limits. One such limit is the modeling – having a good model is crucial. The other limitation is the computing capacity: during the simulation based analysis of ICT and connected BP systems we may easily be faced with the cases where the calculations exceed the sensible amount. A solution here may be to select the simulation cases better (less 'waste of time' simulation), and, to apply simplifications to the simulated model.

The main motivation for the authors – working on the problems of evaluation of ERP (Enterprise Resource Planning) systems and of information retrieval systems – to start the research described in the paper was the lack of methods to measure and manage the efficiency in the process of execution of modelling and simulation, in a manner taking into account both the short-term and long-term points of views: the efficiency of each methodological step and the requirement of reducing the number of iterations (the number of methodological cycles).

In this paper we tackle with a simulation meta-methodology, so, the methodology of designing the simulation of complex systems. The focus here is not on the meta-methodology itself – it has been already published and examined extensively [15–17] –, but, on a new approach for performing one of its steps, namely, to decide how to select the next action in the actual problem context. We propose a model, and prove that it is effective and convergent under sensible conditions.

The paper is organized as follows. Section 2 summarizes the basic concepts that will be used throughout the paper. Section 3 defines the new problem context retrieval model formally. Section 4 analyzes the model from the point of view of the efficiency principles. Section 5 provides stop criteria and convergence conditions for the process. Section 6 discusses further practical and theoretical aspects, including evaluation results. Section 7 concludes the work.

2 Basic models of simulation methodologies, problem contexts and efficiency

The analysis of ICT and BP systems has an extensive theoretical background. In this section we summarize the most important definitions and approaches, as well as our extensions to them.

2.1 The simulation methodology and the methodological aspect of efficiency

According to the classic definition, simulation is a process of developing a simulation model of the system of interest and performing experiments with the model in order to reach the defined goals.

The *process of simulation* lasts from the definition of goals of simulation – starting from the identification and investigation of the need for developing a simulation model of a system of interest – to providing support for the implementation of results of simulation [20].

In an *organizational environment*, the process of simulation may be looked at as a *project process*, initiated to reach the defined goals, within time and cost limits and with the required quality. The simulation process in an organizational environment is a *participative* and *collaborative* process with many *participants* [21]. Sierhuis and Selvin define the simulation process as a holon in terms of Soft Systems Methodology (SSM) [2, 22]. (More details on SMM will be given later in this section.)

In our approach, the *simulation methodology* is a *structured set of methods* that are applied by a *Human Activity System (HAS)* [2] performing the process of simulation.

The efficiency of simulation may be influenced by many factors. For us, the most important influencers are the *methodological factors*. For example, the occurrence of *unstructured problems* and the problem of *efficient applicability of methods* are such methodological factors.

The goal of the paper is to analyze the requirements for a Simulation Meta-Methodology (SMM), which can successfully deal with the performance management of simulation on meta-level, on the level of methods.

2.2 Problem context types

Jackson and Keys describe the two-dimensional categorization of **problem contexts** for the examination of problem situations in the analysis of systems [10]. Problem contexts are classified according to two dimensions:

- the *simple-complex* dimension describes the *system feature* and
- the *unitary-pluralist* dimension characterizes the *actors feature* of the problem context.

According to this classification, the *problem contexts* may be: *simple-unitary, simple-pluralist, complex-unitary and complex-pluralist*. The simple-unitary context is a special case of the complex-unitary and of the simple-pluralist context and all these three contexts are the special cases of the complex-pluralist context.

In the methodology, proposed by Jackson and Keys, first, the dimensions of the problem context should be defined and then the most suitable to the defined problem context methodology should be selected. (Jackson also examines and proposes methodologies suitable to different problem contexts. For example, to the *complex-pluralis*t problem context Flood and Jackson proposes Checkland's SSM [7].

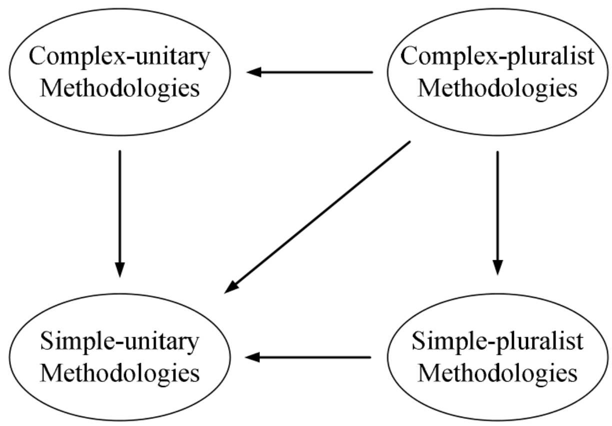

Fig. 1. Restriction relations of scopes of methodology types

Methodologies, which are suitable for complex-pluralist problem contexts, are potentially able to address problems in all other problem contexts but using methodologies for complex-pluralist problem contexts in other problem contexts may lead to *inefficiency*, to waste of efforts and resources [10].

For the further analysis, the Restriction/Extension relationship of scopes of methodologies will be defined as it is shown in Fig. 1.

2.3 Hard- and soft-systems methodologies

According to Checkland, methodologies may be classified as hard-and soft-systems methodologies [1]. **Hard-systems methodologies** are looking for *solutions* to *problems*, **soft-systems methodologies** are oriented to *learning about the problem situations*. A hard-systems methodology *may loose touch* *beyond the logic of the problem situation* and works only with *hard information* while a soft-systems methodology keeps in touch with the *full content* of the problem situation, including human aspects with soft information [5]. The scope of the soft-systems methodology shows the general case of which the scope of the hard-systems methodology is a *special case*. Soft-system methodologies may make accessible some hard aspect of the problematic situation through *occasional condensing*.

It is important for the definition of features of SSM, that occasional condensing can lead to the *loss of information* about the problem situation.

2.4 Deriving the hard-soft categorization of problem contexts

Now, we derive *the hard- and soft categorization of problem contexts* and establish the relationship with the two-dimensional categorization. Problem contexts could also be differentiated on the bases of the methodologies that are appropriate to the problem contexts. Hard-systems methodologies are suitable for looking for solutions to well-defined problem situations, starting from clearly defined objectives. Thus *simple-unitary problem contexts* with well defined system features and with a common set of goals of decision makers are *hard problem contexts*. Soft-systems methodologies are to cope with ill-defined, unstructured problem situations, in which objectives are themselves problematical. The *complex-pluralist problem contexts* with not defined system feature and with pluralist set of decision makers are *soft problem contexts*. The *complex-unitary* problem context may have an active purposeful part and thus it will also require a soft-systems methodology for learning the situation therefore this problem context can be classified as a *soft problem context*. The *simple-pluralist* problem context requires a soft approach to deal with the pluralist set of decision makers that is it is a *soft problem context* too.

2.5 Defining the two-dimensional problem context model of simulation of organizational ICT and BP systems

2.5.1 Simple-Complex Dimension (System Features)

Taking into account the views of Vemuri with the remarks of Jackson and Keys on the differentiation of systems [10, 24] as the starting approach, the system features – which determine the simple-complex dimension of the simulation problem contexts in the modeling and simulation of organizational ICT and BP systems – are identified as follows:

- Systems of interest are often only partially observable: this may be caused by data availability problems (for example: data are not collected or cannot be collected because of technical reasons, cost, time and resource limits; collected and available data are enough only for partial description of the system; data sources may be located in other systems and are not available for the modeling purposes, etc.).
- The wide boundaries of the models of systems of interest and their high resolution too (including both structural and time resolution) may make the problem complex: the wider the boundary is set the more complex the system may become and the same is true for the resolution.
- The complexity is increased by taking into account the influences among systems (including the influences between ICT and related BP systems). Interacting systems are open to influences between each other. The more detailed the model of interactions is the more complex the system may become.
- BP systems may have active, purposeful parts: their behavior cannot be predicted exactly (for example people in the system may act in opposition to simulation project goals).

A simulation problem context is simple if the systems of interest are observable, the boundaries and the resolution of modeling of the systems are set at a necessary but low level, the influences among the systems of interest are limited in the model (systems are reasonably closed) and the purposeful parts of processes are passive. Any of the above four conditions may make the simulation problem context complex: if the systems of interest are not observable (partially observable), the boundaries and the resolution of modeling of the systems are set at a too wide/high level for simulation, the influences among the systems of interest are not limited enough in the model (systems are open) and the purposeful parts of processes are active.

In determination of system features the emergent properties [12] have to be taken into account too: for example, the boundary for modeling should be set wide enough and the resolution of models high enough to examine the emergent properties and to get the necessary answer – and the boundary should be narrow enough and the resolution low enough to be able to simulate the system.

The probabilistic feature of the behavior of systems – which is the basic object of the simulation analysis – should be examined with respect to the uncertainty that may occur.

2.5.2 Unitary-pluralist dimension (actors feature)

Simulation problem contexts are problem environments formed by many participants, because the simulation process is usually a participative and collaborative process. The actors of the simulation problem contexts are determined by the simulation project and the organizational environment. The role of an actor – from the point of view of the problem context – may be the role of decision maker and the role of problem solver. The problem context is unitary if the set of decision makers have a common set of goals and pluralist if they do not; that is the set of decision makers is unitary (agree) or pluralist (disagree). Problem solvers (users, analysts, modelers, etc.) may also be decision makers in different phases of the simulation process.

2.6 The problem context approach and the scope of the traditional simulation methodology

We propose a novel approach for the challenges described above. The basic idea is to model problems in means of their problem context, and select suitable methodologies to solve them, dynamically, based on their actual context only. The main advantage of this approach is that it enables us to better understand why and how certain methodologies are better for a concrete problem instance; and, enable us to deal with the occurring complications dynamically, even in cases when the classic approach would fail.

- For the SMM, instead of the rather static approach of Jackson and Keys – defining one problem context and selecting one suitable methodology – we propose a dynamic approach: different problem contexts may occur in dealing with a problem situation which, of course, may require different suitable methodologies. (The two-dimensional problem context model of simulation of organisational ICT and BP systems introduced above proves the possibility of occurring any problem context.)
- In the dynamic approach, the problem contexts defined by Jackson and Keys are taken as problem context types which may contain many problem contexts (and the problem contexts may contain the problems associated with the analysed problem situation).
- The traditional simulation methodology is a hard-systems methodology appropriate only for simple-unitary problem context [9, 10]. SMM should cope with all other problem contexts and even in a dynamic manner.

2.7 Systems approach to efficiency

Efficiency is our main point of measurement when talking about a system's performance, hence, the definition of this measure is very important.

According to Checkland's systems approach of efficiency [2], performance of systems should be evaluated using three criteria: efficiency, efficacy and effectiveness.

- *Efficiency* is the measure that shows the relationship of the output to the resources used.
- *Efficacy* is the measure telling whether the required effect has occurred or not.
- *Effectiveness* measures how the system meets longer term aims.

2.7.1 The four efficiency principles

On the basis of systems approach of efficiency and adding the requirement of avoiding loss of information we develop the efficiency principles of SMM.

The *principle of methodological efficiency* (**principle e_1**) may be formulated as follows: for a method to be efficient the best fit with a specific problem context should be found.

It may happen that some problem context will not fit into any one of the problem context types that is the problem of inefficacy occurs. In this case, the given method may be hardened up or softened up, in order to find the exact fit, and to avoid inefficiency. This is the *principle of hardening up and softening up* (**principle e_2**). For example, in a problem situation where a soft-systems approach is used to a complex-pluralist problem context, it may be found that it would be useful to harden up the methodology to deal with some hard aspects of the problem context: for instance, it may happen in the problem structuring phase of an ICT-BP system evaluation simulation project, that it is necessary to involve a statistical analysis method of some CRM (Customer Relationship Management) data to learn and understand better the performance behaviour of the ICT-BP system.

The *principle of methodological effectiveness* (**principle e_3**) expresses the efficiency requirement for the whole process of simulation. According to the systems approach of efficiency, it is required to fit the simulation process (simulation project) with the requirements of the wider systems environment and it is necessary to examine the execution of a phase of the simulation in the environment of the whole simulation process. As a result from the point of view of efficiency, the reduction of the number of iterations may be reached and the bottlenecks may be avoided.

A methodological gap (possibility for loss of information) may occur in the execution of the process of simulation if a soft-systems method and a hard-systems method is applied for two sequencing problem contexts where the appropriate and structured set of hard-level information – which will be processed by some hard-systems method – is produced from the set of soft-level information by using a complex set of constraints for condensing.

The methodological gap may be eliminated by constructing a methodology connecting the soft and hard levels – for example by hardening up the soft-systems method – by adding a method which supports condensing according to the requirements of the hard-systems method. This approach may be called the *principle of elimination of the methodological gap* (**principle g**).

In the following, we introduce a model which helps to determine SMM features which allow to manage the performance of simulation successfully on meta-level. In the model, the concept of dynamic problem contexts for simulation and the efficiency principles formulated above are used to answer the following questions:

- How to process problem contexts using the smallest amount of methodology cycles (reduction the number of iterations)? (point 4.3)
- How to process problem contexts with a decreased amount of waste of resources? (points 4.1-4.4)
- How can every problem context be processed? (points 4.3, 5.1, 5.2)

- How to prevent information loss which may occur in condensing (completeness of condensing)? (point 4.4)
- What are the long-run features of SMM (stopping criteria, convergence)? (points 5.1, 5.2)

3 SMM with a problem context retrieval model

This section presents our problem context retrieval based SMM model alongside with the analysis of its most important properties and effects. We use the principles defined in the previous chapter – e.g. efficiency principles – for evaluation.

3.1 The problem context retrieval model

The basic idea of the model is that determining the actual problem context is – in a certain way – similar to the challenge of information retrieval. In case of information retrieval, a matching set of documents should be retrieved for a query. Here, a useful and appropriate set of problem contexts should be retrieved for the problem situation (usefulness and appropriateness will be defined later).

Assuming that problem contexts are similar to documents that should be retrieved; and, all the problem contexts related to the *problem situation* form a set that may be targeted in retrieval, then, a *problem context retrieval model* – similar to an information retrieval model – can be built for the analysis of SMM.

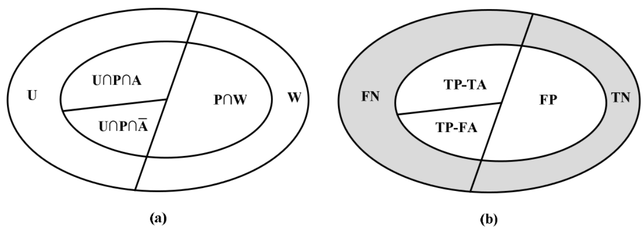

Fig. 2. Sets of the problem context retrieval model

Fig. 2(a) shows the sets of the problem context retrieval model:

- U is the set of "Useful" problem contexts – contexts which can be useful for the answer to be produced by SMM for the problem situation,
- W is the set of "Waste-of-time" problem contexts – which are waste of time from the point of view of the answer to be produced by SMM.
- X is the set of problem contexts – set of all the potentially important problem contexts in the given problem situation.

In our approach, it is not enough to find problem contexts, but it is also a requirement that we should process these contexts properly. For example, in case of information retrieval, the retrieved document is not of much use if it is written in a language that the reader cannot understand. (The same way, if the problem context cannot be processed properly, it is not useful.)

- P is the set of problem contexts that have been found, and processed by SMM.
- A is the set of found and appropriately processed problem contexts.(We shall tackle with the appropriateness of the processing later.)

Further sets are defined as:

- C is the set of categories of problem context types in the two dimensional model of problem contexts
$$C = \left\{c_{su}; c_{cu}; c_{sp}; c_{cp}\right\} = \{c_1; c_2; c_3; c_4\} = \{1; 2; 3; 4\}$$
- The set X is a union of the two disjoint sets U and W
$$X = U \cup^* W, (U \cap W = 0),\ x_{c(i)} \in X,$$
$$c \in C, i = 1, 2, \ldots, |U \cup^* W|$$
- Furthermore, it is supposed in the model that $|U \cup^* W| = const$.
- X_{SMM} is the set of problem contexts that retrieved by SMM ($X_{SMM} \subseteq (U_{SMM} \cup^* W_{SMM})$)
- M is the set of methods of SMM including all the method (methodology) types:
$$M = M_{c1} \cup M_{c2} \cup M_{c3} \cup M_{c4}$$

For more details on the elements and the set of methods of SSM please refer to [15–17].

Fig. 2(b) depicts the model using the typical sets of information retrieval (classification).

- FN = False Negative
- TN = True Negative
- FP = False Positive
- $TP - TA$ = True Positive – Appropriate
- $TP - FA$ = True Positive – Inappropriate sets which are connected to appropriateness. The following equations may be set:
$$FN = |U \backslash ((U \cap P \cap A) \cup (U \cap P \cap \overline{A}))|,$$
$$TN = |W \backslash (P \cap W)|, FP = |P \cap W|$$
$$TP - TA = |U \cap P \cap A|$$
$$\text{and} \quad TP - FA = |U \cap P \cap \overline{A}|$$

Comparing the (a) and (b) side of Fig. 2, one can easily see the relationship between the classic information retrieval and the problem context retrieval model. Each of the classic information retrieval model's subset has a parallel in the problem context retrieval model, with the same properties.

The effectiveness of information retrieval may be characterized by its *recall (r)* and *precision (p)*. We utilize these two metrics in our model. According to our model, they are defined as:

- Recall : $r = \frac{|P \cap U|}{|U|}$ and
- Precision : $p = \frac{|P \cap U|}{|P|}$

3.2 Functions of SMM

At this point, we define the functions of SMM which are necessary for the analysis.

3.2.1 Identification function

The Identification function serves for the classification of problem contexts according to types of problem contexts:

- $f_I : X \times C \to \{0; 1\}$
- $f_I(x_i; c_j) = 1$, if the problem context x_i is of c_j type, $i \in \{1; 2; 3; 4\}$ and $j \in \{1; 2; 3; 4\}$
  $f_I(x_i; c_j) = 0$, otherwise

3.2.2 Processing function

The Processing function assigns methods to problem contexts for processing:

- $f_P : X \to M$
- $f_P(x_i) = m_j$

3.2.3 Generation function

After processing, the Generation function generates a problem context which may be of any type:

- $f_G : X \times M \to X$
- $f_G(x_i; m_j) = x_k$, where x_k is the next problem context to process and $i \in \{1; 2; 3; 4\}$, $j \in \{1; 2; 3; 4\}$ and $k \in \{1; 2; 3; 4\}$

3.2.4 Generation function by insertion

The insertion function is intended to take account of the problem context that may occur from the external environment of the SMM work (from outside of the simulation project). It may be described, for example, as a probabilistic action:

- $f_{G(Insertion)} : (X \times M_4) \times \Omega \to X$
- $f_{G(Insertion)}(x_{insert}; m_j; \omega) = x_k$, where x_k is the next problem context to process, $x_{insert} \in X_{insert} \subset X$,
- $m_j \in M_4$, (the insertion may be executed only by a complex-pluralist method) and $\omega \in \Omega$ (ω is an elementary event of the Ω sample space).

3.2.5 Appropriateness function

Appropriateness functions test whether the processing of a problem context was appropriate or not:

- $f_A : X \times M \to \{0; 1\}$
- $f_A(x_i; m_j) = 1$, if the problem context and the method are of the same type ($i = j$), $i \in \{1; 2; 3; 4\}$, $j \in \{1; 2; 3; 4\}$
  $f_A(x_i; m_j) = 0$, otherwise

Test of appropriateness may take place at the end of a methodological cycle of SMM.

4 Effect of efficiency principles on problem context retrieval

This section analyzes the problem context retrieval model along the efficiency principles (defined in section 2.7). Instead of providing detailed mathematical analysis, at some points, we are using examples to showcase a certain phenomenon.

When talking about efficiency, we do not separate single steps. The whole process shows a flow-like behaviour: we identify a problem context, select an available and appropriate methodology to solve it, then, during the solution another sub-problem occurs and we have to identify its sub-problem context and its solution methodology, and so on. To make this more visual, let us think of the original document retrieval example: we want to look up which team was the winner of the Football World Cup in 2010. The retrieved result set contains the answer, but, unfortunately, it is written in Hindi which is a language we cannot understand directly – but, luckily enough, we do have a translation service. So, in order to make the document useful, we have to apply an intermediate processing step: translation from Hindi to English. It might also be a case that the translation cannot be done directly, but further intermediate steps are needed (Hindi to Chinese, then Chinese to English). The same way, the solution to a problem may tear down to a series of resulting sub-problems, and, for each of these problems, we apply the same approach of methodology selection.

The flow-like operation is not only present at the level of single problem contexts. The solution of a problem – either directly or via teardown into subproblems – will result in a new problem instance, and everything starts from the beginning. (In the end, the retrieved context for the new problem instance will be empty, either because we reached and ultimate solution or because there is nothing more to do.)

4.1 Effect of Principle "e1"

Efficiency refers to the resources utilized during the solution; it describes how good or lavish the resource usage was. By resources we mean the methodology choice. For example, an m_4 methodology is a universal tool, it is able to process any problem instance – but, in most cases, it is better to apply a cheaper methodology (e.g. m_1 for a simple-unitary problem).

4.1.1 Effect of using methods suitable for problem context types

The first interesting aspect of our model is that the methodology choice should not be blindly transferred to the sub-problem. To understand it better, we created a showcase example, where four independent original problems – each with a different methodology complexity – are torn down into sub-problems (like Hindi-Chinese translation in the example). Let us consider the case when one of the sub-problems happens to be the same in all four cases. If the methodology's complexity is blindly transferred to the sub-problem, we shall face the same challenge with four differently complex methodologies – which will in most

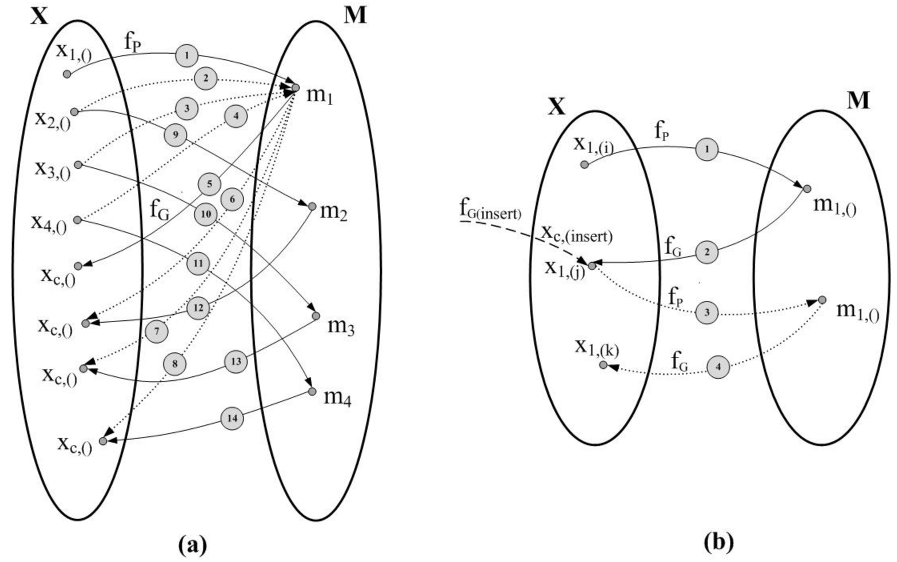

Fig. 3. Effect of the methodological efficiency principle

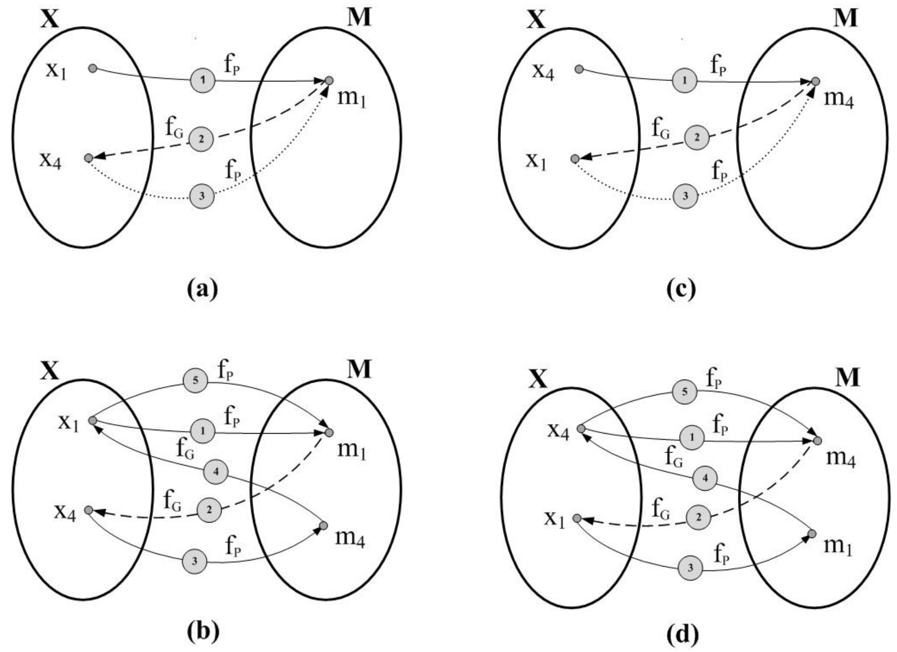

Fig. 4. Effect of methodological efficacy(Principle of hardening-up and softening-up)

cases turn out to be either wastefully strong or too weak to solve the sub-problem properly.

In Fig. 3(a) transitions numbered by 1, 2, 3 and 4 are generated according to processing functions

$$f_P(x_{1,()}) = m_1, f_P(x_{2,()}) = m_1$$

$$f_P(x_{3,()}) = m_1, f_P(x_{4,()}) = m_1$$

For transitions 2, 3 and 4 $f_A(x_i; m_j) = 0, (f_A(x_i; m_j) = 1$ only for the $x_{1,()}$ and m_1 processing $(i = j)$) thus they increase $|U \cap P \cap \overline{A}|$, furthermore transitions 6, 7 and 8 that is generation of $x_{c,()}$ problem contexts will increase $|P \cap W|$.

In case of transitions 9, 10 and 11 in Fig. 3(a),$f_A(x_i; m_j) = 1$ because the methods suitable for problem context types are used (increase of $|U \cap P \cap A|$), and thus the problem contexts $x_{c,()}$ generated according to transitions 12, 13 and 14 will increase $|U \cap P|$, which occurs as the decrease of $|P \cap W|$.

4.1.2 Effect of insertion

In Fig. 3(b) the effect of insertion is shown. Processing of $x_{1,(i)}$, $x_{1,(j)}$ and $x_{1,(k)}$ is executed by methods $m_{1,()}$. Accordingly, problem context $x_{1,(j)}$ will be generated and processed instead of $x_{c,(insert)}$ because $m_{1,()}$ cannot realize insertion: it is beyond the scope of methods of this type. This way, processing of $x_{1,(j)}$ and $x_{1,(k)}$ will increase $|P \cap W|$. (This can be the case for any series of methods $m_{c,()}$, $c < 4$.)

Improvement can be the introduction of *alternation* that is to change the method type to type-4 periodically. Too frequent alternation may also increase $|P \cap W|$. To avoid this decrease of efficiency, the frequency of alternation should be fitted to the frequency of occurring of insertion.

4.2 Effect of principle "e_2"

Efficacy measures if the required effect has occurred or not.

In this aspect, we showcase the situation when the original problem context turns out to be less clear than originally thought, so, the methodology choice, hence achieving success is not so easy.

Fig. 4 shows situations when a method cannot process a problem context without generating an *intermediate* one (transition number 2 in Fig. 4(a) and Fig. 4(c). If the processing of problem contexts x_4 and x_1 will be executed according to transition 3 in Fig. 4(a) and Fig. 4(c)) then $f_A(x_4; m_1) = 0$ and $f_A(x_1; m_4) = 0$ for these situations, thus $|P \cap U \cap \overline{A}|$ will be increased. These situations correspond to problem contexts which cannot be easily categorized according to our four problem context types (*multilabel* problem contexts) and which contain "latent" problem context.

Improvement for similar situations is shown in Fig. 4(b) and Fig. 4(d) and may be described using formula

$$f_P = (f_{P(5)} \circ f_{G(4)} \circ f_{P(3)}[f_{G(2)} \circ f_{P(1)}])(x_4)$$

in which $[f_{G(2)} \circ f_{P(1)}]$ is the generation of the latent problem context.

The softening-up and hardening-up are:

- $f_P : \{x_4\} \rightarrow \{m_1\}$ will be replaced by $f_P : \{x_4\} \rightarrow \{m_4\}$ softening-up
- $f_P : \{x_1\} \rightarrow \{m_4\}$ will be replaced by $f_P : \{x_1\} \rightarrow \{m_1\}$ hardening-up

For this improvement the set of methods should contain for every processing *available* methods for softening-up and hardening-up a given method.

4.3 Effect of Principle "e_3"

Effectiveness measures how a system meets long-term goals. It often happens that a certain step is locally suboptimal, but on the long term, it leads to a better general performance.

We examined the effectiveness in means of convergence. The questions asked were: when does the flow end? What can we say about the number of steps needed for that, and about the optimality of the process?

Using principle e_3, SMM may find the right set of problem contexts to process thus this principle helps SMM in using the smallest amount of processing steps and in reduction of the number of iterations (number of methodological cycles).

4.3.1 Modeling the SMM flow

The flow of emerging contexts and emerging successor problems can be modeled with the help of further functions.

Using the function f_{GS} according to the set of goals $G = \{g_1; g_2; \ldots; g_{|G|}\}$ and to the set of initial problem contexts $\{X_{initial}\}$ for simulation project, the set of problem contexts to

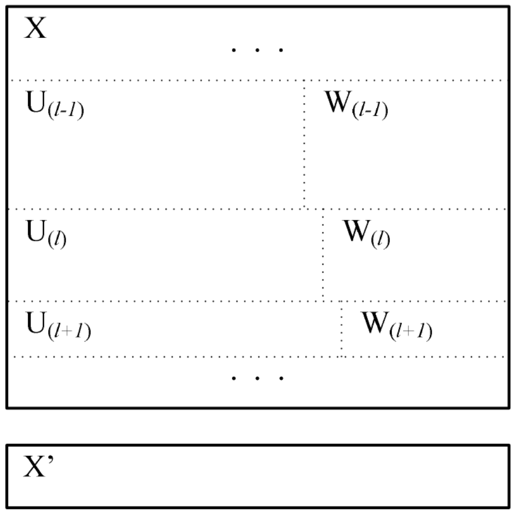

Fig. 5. The effect of the methodological effectiveness principle

process can be defined for the starting methodological cycle $\left\{inf\ X; supr\ X; \frac{|W|}{|U|}\right\}$.

The function f_{GS} has the following form:

$$f_{GS} : \{g_1; g_2; \ldots;_{|G|}; X_{initial}\} \rightarrow \left\{inf\ X; supr\ X; \frac{|W|}{|U|}\right\}_{start}$$

About the fast, approximate methods that allow making this prediction you may read in [13].

Using function f_{ISF} for implementation support, based on the observed data of the present cycle the predicted data for the next methodological cycle should be defined:

$$f_{IS_l} : \left\{(U \cap P); (U \cap P \cap A); (P \cap W); \frac{|U \cap P|}{W \cap P|}\right\}_{l(observed)} \rightarrow \left\{inf\ U; supr\ U; inf\ W; supr\ W; \frac{|W|}{|U|}\right\}_{(l+1)(predicted)}$$

(This way, the number of iterations may be reduced.)

Without the use of f_{IS}, a situation shown in Fig. 5 may happen: a new set of problem contexts (X') may occur decreasing $|P \cap U|$ and increasing $|P \cap W|$.

The whole process may be described using the next formula:

$$((f_{IS} \circ)^l) \circ f_{GS}(g_1; g_2; \ldots; g_{|G|}; X_{initial}) = (inf\ U_{l+1}; supr\ U_{l+1}; inf\ W_{l+1}; supr\ W_{l+1}; \frac{|W|}{|U|}_{l+1})$$

where $(f_{IS} \circ)^l$ defines the use of f_{IS} l number of times (l denotes the last, observed methodological cycle.

Using the prediction, we may also decide about the problem contexts in the set $P \cap U \cap \overline{A}$.

4.3.2 Stopping criterion based on e_3

The function f_{IS} may also be used to define stopping criterion for SMM by calculating the shift of U (set of Useful problem contexts):

$$\Delta u_{l+1} = 1 - \frac{|U_{l+1} \Delta U_l|}{|U_{l+1} \cup U_l|},$$

if $\Delta u_{l+1} \leq \Delta u_{limit}$ then the SMM process may be stopped.

4.4 Effect of principle "g"

The methodology gap refers to the possible loss of information when a soft and a hard system method are applied consecutively. In this view we examine if there is any information loss in the hardening – up and softening – up steps.

Fig. 6(a) gives an example for such an information loss. In the example, $x_{4,(i+1)}$ generated by $f_G(x_{4,(i)}; m_4)$ (transition 2 in Fig. 6(a)) will be processed by $m_{1,(0)}(m_{1,(0)} \in M_{local(2)}, f_A(x_{4,(i+1)}; m_{1,(0)}) = 0)$ which is the case of *condensing* and may lead to loss of information. $M_{local(2)}$, the available set of methods contains only hard-systems methods, thus further generation and processing (transitions 4-9 in Fig. 6(a)) may increase $|P \cap W|$.

However, information loss can be avoided when the change is executed properly. The improvement for this problem is shown in Fig. 6(b): $x_{4(mcm),(i+1)}$ generated by $f_G(x_{4,(i)}; m_{4(mcm)}$ (transition 2 in Fig. 6(b) will be processed by $m_{1(mcm)}(m_{1(mcm)} \in M_{local(2)})$. The method mcm (Modified Conceptual Modelling [15]) is available both for $M_{local(1)}$ and $M_{local(2)}$ (soft and hard levels). The problem context $x_{4(mcm),(i+1)}$, containing the requirements of hard level, helps to generate and process the proper problem contexts which are $(x_{1(j)} - x_{1(q)})$ in Fig. 6(b).

5 Stopping criteria and convergence of SMM

This section examines the convergence of the SMM process in more details.

5.1 Stopping of the SMM process

The outcomes of an SMM step may be: (1) the problem disappears, (2) a soft solution (Accepting Desirable and Feasible change of SSM, [2] is formulated, (3) the structuring the problem situation to the problem context of running the hard simulation methodology is successful.

We provide two different ways to define the stopping criteria:

- The *stopping criterion (a)* may be defined in the way described in the analysis of principle e_3.
- The *stopping criterion (b)* may be the result of getting x_0^* in a transition.

Let us introduce x_0^* as the empty problem context with the following features:

$$x_0^* \in U \cap P \cap A;\; f_P(x_0^*) = m_0^*$$

$$m_0^* \in M_4 \text{ and } f_A(x_0^*; m_0^*) = 1$$

The empty problem context may be generated by any type of method:

$$x_0^* = f_G(m_1) \vee f_G(m_2) \vee f_G(m_3) \vee f_G(m_4)$$

If the methodological efficacy applied for the X_{SMM}

$$(\Phi^\circ)^k(x_{initial}) = x_0^*$$

where k is the number of problem context transitions for processing the set X_{SMM}.

5.2 Convergence of SMM

In this section we show that, under certain conditions, the SMM flow is convergent. Precision and recall metrics will be utilized for the proof.

The classic measures of precision (p) and recall (r) for problem context retrieval may be calculated as average values according to formulas

$$p = \frac{\sum_{l=1}^{L} \sum_{i=1}^{|C|} |P \cap U|_{i,l}}{\sum_{l=1}^{L} \sum_{i=1}^{|C|} |P|_{i,l}}$$

$$r = \frac{\sum_{l=1}^{L} \sum_{i=1}^{|C|} |P \cap U|_{i,l}}{\sum_{l=1}^{L} \sum_{i=1}^{|C|} |U|_{i,l}}$$

where $|C|$ is the number of problem context types (for our case $|C| = 4$) and l is number of cycles ($l = 1, 2, \ldots, L$).

The Rijsbergen [23] composite effectiveness measure may be calculated as:

$$E = 1 - \frac{1}{\frac{1}{r} + \frac{1}{p} - 1}$$

Let us introduce the composite measure

$$E = 1 - \frac{1}{\frac{1}{r} + \frac{1}{q} - 1}$$

where instead of precision p, the measure q (depending on the relationship between $|W \cap P|$ and $|U \cap P|$) is used.

We shall show that

$$E_L = \lim_{L \to \infty} 1 - \frac{1}{\frac{1}{r_L} + \frac{1}{q_L} - 1} = 0$$

E is a strictly decreasing function of the independent variables r and q $\left(\frac{\partial E}{\partial r} < 0, \frac{\partial E}{\partial q} < 0\right)$ and

$$E = \lim_{r;q \to 0} 1 - \frac{1}{\frac{1}{r} + \frac{1}{q} - 1} = 1$$

The value of recall is a monotonically increasing function of the number of cycles thus $\lim_{L\to\infty} r_L = 1$.

Now, let us examine the value of q. The value of q may be expressed as

$$q_N = 1 - c_N,$$

where N is the number useful problem contexts produced by L cycles

$$N = \sum_{l=1}^{L} |P \cap U|_l$$

The process of SMM – as a *HAS system process* – may be characterized by a *learning function* (which is a power function of the management theory):

$$c_N = c_1\, N^{-e_{(y,x)}}$$

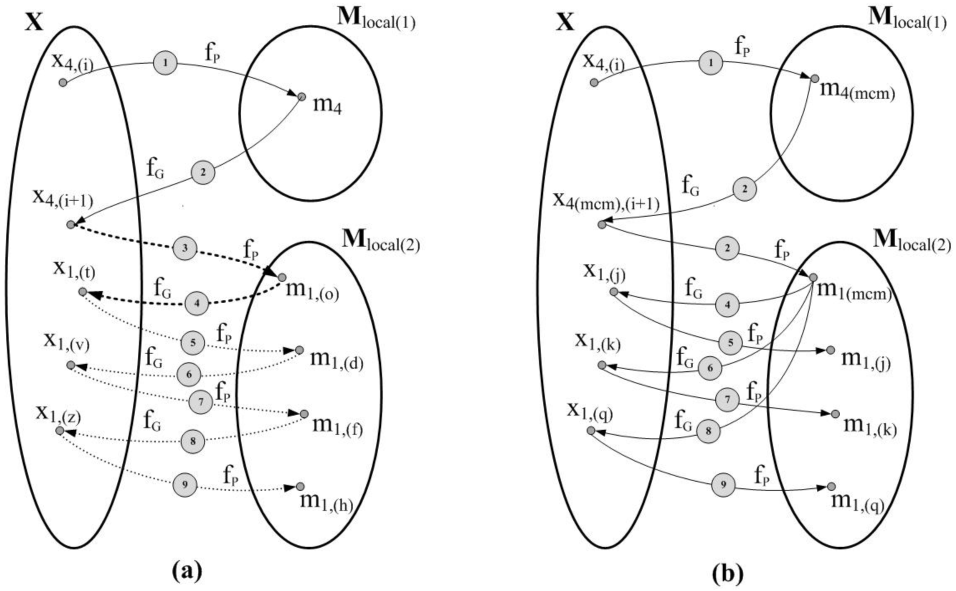

Fig. 6. The effect of the methodological gap (Principle of elimination of the methodological gap)

where c_1 is the starting cost, c_N is the Nth cost, and $e_{(y,x)} = \left|\frac{\partial \ln(y)}{\partial \ln(x)}\right|$ is the elasticity of y regarding to x.

(The *learning effect* occurs in traditional information retrieval systems too [4].)

In our case, c_1 and $e_{(x,y)}$ may be calculated using the observed values of $|P \cap W|$ and $|P \cap U|$ during the first methodological cycle. (The $|P \cap W|$ is viewed as the cost to produce $|P \cap U|$ useful problem contexts.) The value of c_N is a strictly decreasing function of N series of c_N thus $\lim_{N\to\infty} q_N = 1$, therefore E_L converges to 0.

In other words, as HAS systems have an ability to learn, they will be able to operate the SMM process in a sensible way, guaranteeing, that in each step, either the precision or the recall of the retrieved problem context will be increased. Then, Rijsbergen's method – based on the series of differences – was used to prove that this process is convergent.

6 Discussion

This section discusses further theoretical and practical aspects of the proposed approach, including its real-life evaluation.

6.1 Related work

The approaches that are closely related to the approach described in the paper are multi-methodological systems approaches using meta-level selection of methods for the increase of efficiency.

These systems approaches can be grouped into two main categories:

Problem context based approaches: the SOSM (System of Systems Methodologies) [10, 11], the SOSF (System of Systems Failures) [18], the TSI (Total Systems Intervention) [7, 11], the CF (Complementarist Framework) [6] and the CDM (Creative Design of Methods) [14] belong to the group of the problem context based methodologies.

All of these approaches are inherently multi-methodologies. These methodologies use the concept of problem context types for the classification of problem contexts according to system and human features. These approaches provide a set of preliminarily evaluated and classified methods for each problem context type.

All of these methodologies are rather static approaches: the basic concept of these approaches is the selection of one suitable method for a context, or for an aspect of a context. In case of unclassifiable contexts, only a limited correction is allowed which may lead to inefficiency in a problematic situation. These methodologies do not provide formal concept of efficiency. In these methodologies, there are no tools offered to support problem context classification.

Approaches based on the soft systems concept of SSM: LSSM (Logical Soft Systems Modelling) [8, 19] uses enhanced conceptual models (logico-linguistic models) to interface with other methods (including hard methods). Different ways for building a multi-methodology on the basis of SSM are grafting and embedding. SSM with grafting integrates other method(s) into model building stage of the SSM [26]. In case of SSM with embedding, SSM is used as a meta-methodology to control the methodological process [25].

These approaches use the tools of the Soft Systems Methodology (SSM, [2,3]) (rich picture, root definitions, conceptual models and the seven-stage methodological cycle) to support the selection of the next step. All the SSM based approaches use the systems performance criteria of efficacy, efficiency and effectiveness. (LSSM proffers a logical concept of efficiency too.)

The SSM based approaches use only the hard and soft differentiation of problems and, unfortunately, none of these approaches provide a formal model of efficiency.

6.2 Significance of the results

The approach of using the retrieved problem context for modeling the SMM flow is a completely non-traditional, novel direction. We believe it to be a promising one, because of its advantageous properties both in theory and in practice.

- From the theoretical point of view, the benefit of the model is that it is able to explain and model cases that could not be handled by classic approaches. Such cases are for example the teardown of a problem into sub-problem, where using the original problem's methodology is at least not optimal for the sub-problem. Retrieving the actual problem context in each step, and distinguishing between appropriate and wasteful elements is a new and – based on the practical experience – a very useful tool.
- From the practical point of view, we found the model to be natural, and easy to follow. It separates the deep technical details from the practical steps, leads to an efficient communication between teams, and prevents information loss by pointing out the cases where more attention is needed.
- The fact that our model was motivated by the information retrieval models facilitates its deep and accurate analysis. In the last decades, the theory of information retrieval gained significant interest, and, brought a large set of interesting and useful results. As our model shows high similarity with IR, many of these results can be used with minor modifications only.

6.3 Conditions and applicability

The proposed approach is general; no domain-specific restrictions were used. Hence, it is generally applicable for the meta-modeling of any ICT/BP system.

6.4 Evaluation in real-life cases

SMM, with its complex problem context approach and system of efficiency criteria, has been fruitfully used by the authors in several large, real-life projects such as: merge of the ICT and connected BP systems of bank networks, evaluation BCP (Business Continuity Planning) and DRP (Disaster Recovery Planning) of a large service company and evaluation and planning of CRM system of service companies. Based on the authors' empirical experience, this approach performs significantly better than other paradigms aiming to optimize complex, human-included processes.

6.4.1 Case study

To illustrate the application of results described in the paper a case study is provided. The case study describes a project initiated for the performance evaluation and improvement of the Customer Helpdesk (CHD) function of the Sales Organization (SO) of a large telecommunication service provider company. (This project was executed as a part of the BPR (Business Process Reengineering) project of the SO.) The project contained the analysis and change proposal for the BP system and for the CRM system of the SO. In order to evaluate the performance of the CHD the BP system of the SO was modelled and simulated together with the work of its CRM system.

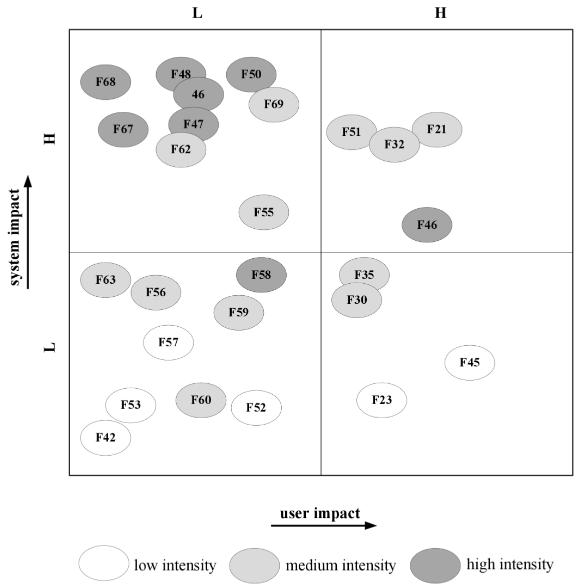

Fig. 7. Process evaluation matrix (The influence of system and user factors on the divergence of BPs)

The structural analysis of the behaviour of the processes showed significant divergences in the execution of the process transitions. For three sample processes (F(a), F(b) and F(c)) the proportions of diverted process transitions were as follows: F(a) - 23.9% diverted transitions (75 prescribed transitions), F(b) - 45.7% diverted transitions (157 prescribed transitions) and F(c) - 40.4% diverted transitions (146 prescribed transitions). (Altogether 24 processes were analysed.)

The system factors (influence of the CRM system) and the user factors (influence of the operators working with the CRM) of the divergence were identified examining the ERP system database. The results of the analysis are shown in Fig. 7: 25 processes are in the process matrix distinguished with their user identifier. In Fig. 7, the vertical axis shows the system impact (systems performance) while the horizontal axis shows the user impact (operators' performance) on the divergence. The intensity of a process defines the urgency of the performance improvement of the given process.

The resulting process evaluation matrix describes the problem context retrieval model of the investigated processes. When both the system impact and the user impact were high (problem context c_{cp}) the change in the system and in user performance required escalation of the decision to a higher level in the organisation (for example: CRM reconfiguration and user training). When both the system impact and the user impact were low (problem context c_{su}), the change decisions could be made on local level. In the project, there were executed nine methodological cycles of the SMM. The main effects of the application of efficiency principles in the project can be summarized as follows:

The principle e_1: besides the determination of problem context types, the design of the set of methods was completed according to the process evaluation map (by including user methods (processes) into set of methods).

The principle e_2: the exact determination of classes of processes (by examining processes crosscutting the organisational boundaries) resulted in a further extension of the set of methods by user methods (processes).

The principle e_3: the implementation was tested by the investigation of the cooperation of processes with other processes of the organisation.

The principle g: the modelling and simulation was executed by two cooperating teams (soft-modelling (with delegated participants of the user) hard-modelling teams).

7 Summary

In this paper we proposed a novel, problem context retrieval based approach for the simulation and modeling of ICT/BP systems, using SMM.

We provided a formal definition for the context retrieval model, including problem context sets along with generator, identification, processing and appropriateness functions. We defined two measures – precision and recall – for the SMM case.

The model was analyzed along the four efficiency principles. The consequence of the analysis is that the problem context retrieval helps in better understanding the cost and efficiency of a problem and its solution, and comes pretty natural for real-life cases.

The methodology was successfully applied for numerous large real-life problems, and was found to largely outperform classic business process optimization approaches.

Our work exceeds the state of the art in the followings. (1) We defined a novel approach for methodology selection in SMM. This problem context retrieval based model is able to explain several complex aspects of the path of finding the solution that could not be handled in traditional models. Such aspects include efficiency leaks of greedy methodology choice, the effect of injections, etc. (2) We provided a formal definition of the approach. (3) We provided detailed analysis of the approach along the efficiency principles. (4) We provided a convergence criterion for the context retrieval based SMM.

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